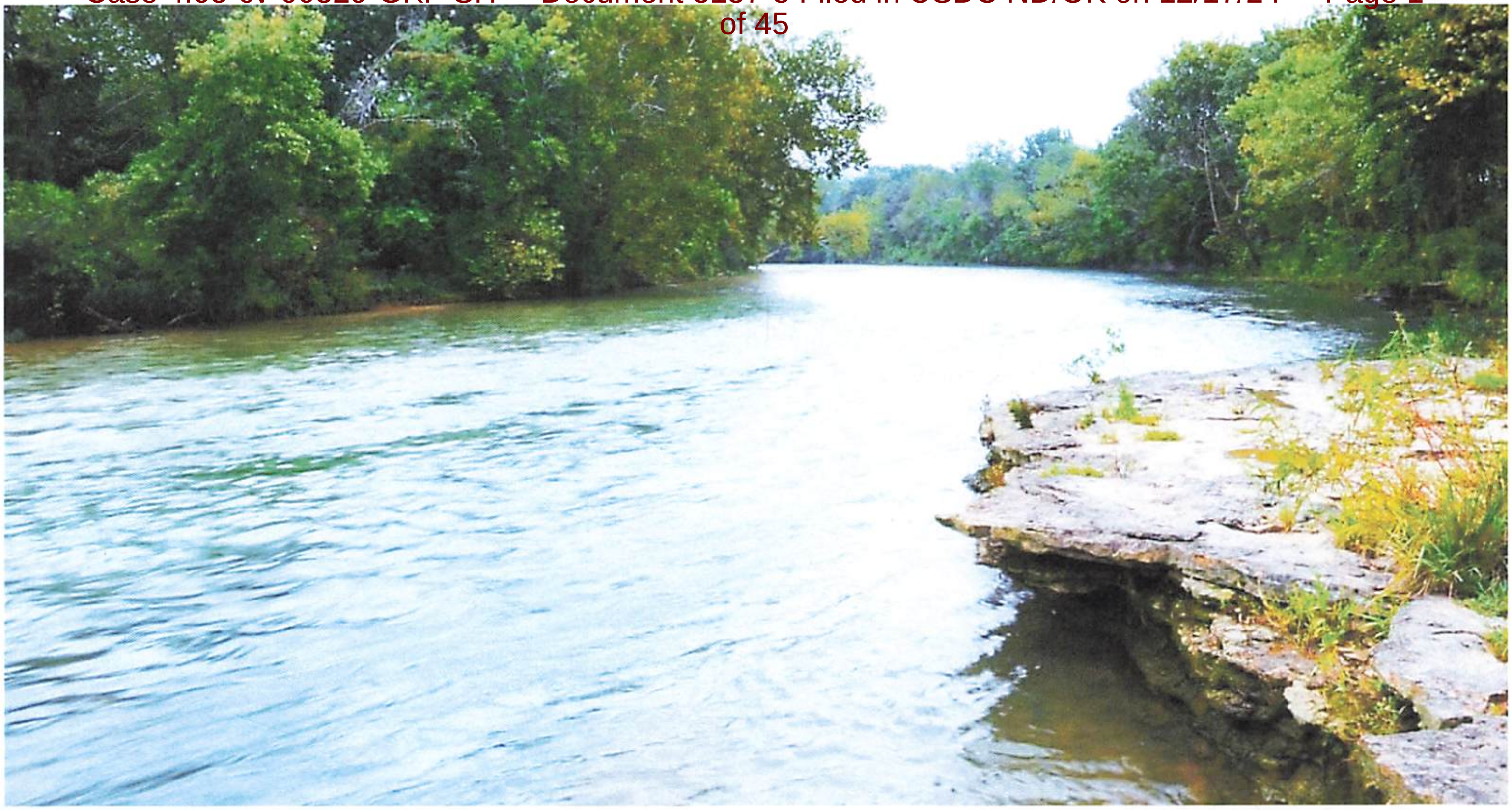


November 2024
Oklahoma Natural Resource Damages Litigation

ANCHOR QEA

Rebuttal Report on the State's SWAT Modeling of the Illinois River Watershed

Prepared for Illinois River Watershed Joint Defense Group

EXHIBIT
COURT
C
05-CV-329-GKFSH

November 2024
Oklahoma Natural Resource Damages Litigation

Rebuttal Report on the State's SWAT Modeling of the Illinois River Watershed

Prepared for
Illinois River Watershed Joint Defense Group
Tulsa, Oklahoma

Prepared by
Jennifer Benaman, PhD
Anchor QEA
68 Excelsior Avenue
Suite 101
Saratoga Springs, New York 12866

Project Number: 240414-01.01

IN THE UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF OKLAHOMA

STATE OF OKLAHOMA, ex rel. GENTNER DRUMMOND, in his capacity as Attorney General of the State of Oklahoma and OKLAHOMA SECRETARY OF ENERGY AND ENVIRONMENT KEN McQUEEN, in his capacity as the TRUSTEE FOR NATURAL RESOURCES FOR THE STATE OF OKLAHOMA,*	)	
Plaintiffs,	)	
v.	)	Case No. 05-CV-329-GKF-SH
TYSON FOODS, INC., TYSON POULTRY, INC., TYSON CHICKEN, INC., COBB-VANTRESS, INC., CAL-MAINE FOODS, INC., CARGILL, INC., CARGILL TURKEY PRODUCTION, LLC, GEORGE'S, INC., GEORGE'S FARMS, INC., PETERSON FARMS, INC., and SIMMONS FOODS, INC.,	)	
Defendants.	)	

EXPERT REPORT OF

Jennifer Benaman

Jennifer Benaman, PhD

* Pursuant to Fed. R. Civ. P. 25(d), Oklahoma's current Attorney General and current Secretary of Energy and Environment are substituted as relators.

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

ABBREVIATIONS

ac	acre
ANRC	Arkansas Natural Resources Commission
Ark.	Arkansas
cfs	cubic feet per second
IRW	Illinois River Watershed
mg/L	milligram per liter
NAS	National Academy of Sciences
NR	not reported
OCC	Oklahoma Conservation Commission
ODAFF	Oklahoma Department of Agriculture, Food and Forestry
Okla.	Oklahoma
OWRB	Oklahoma Water Resources Board
STP	soil test phosphorus
SWAT	Soil and Water Assessment Tool
SWRRB	Simulator for Water Resources in Rural Basins
TMDL	Total Maximum Daily Load
TP	total phosphorus
TSS	total suspended solids
Unk.	unknown
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Service
WBMP	Watershed Based Management Plan
WWTP	wastewater treatment plant
yr	year

1 Declaration

My name is Jennifer Benaman, and I am a Principal at Anchor QEA, an environmental consulting firm headquartered in Seattle, Washington. I am based at our company's Saratoga Springs, New York office. I hold a BS in Civil Engineering from Florida Institute of Technology, an MS in Civil Engineering from University of Texas at Austin, and a PhD in Civil and Environmental Engineering from Cornell University.

For the past 25 years, I have studied the fate and transport of chemicals in surface waters and watersheds. I have had a particular focus on the development and application of watershed models, at times coupled with in-stream water quality models, to understand the impact of non-point source pollutants on surface waters. I have worked on over 35 projects related to studying pollutants in surface waters and watersheds; a number of them applied the Soil and Water Assessment Tool (SWAT) to assess the non-point source loads from the watershed. This work included the application of SWAT to a large agricultural watershed in upstate New York to assess the impacts of dairy farm and manure management on a run-of-the-river reservoir that serves as a drinking water source for New York City. I also led the development and application of SWAT to a series of five reservoirs in central Texas to assess the impacts of development on the nutrient loads from the watershed to the surface waters of the reservoirs.

My watershed and water quality modeling has had a particular focus on the robustness of model calibration efforts combined with understanding the sensitivity of and uncertainty in the model results. My PhD dissertation at Cornell was specifically focused on the sensitivity and uncertainty of the SWAT model and how the model results might be used in light of these uncertainties. I also served on a national expert panel that studied the impact of uncertainty and applying adaptive management to Total Maximum Daily Load (TMDL) implementation in order to manage water quality. This effort was a follow-up to a National Academy of Sciences (NAS) study that assessed the impact of the TMDL process on the improvement of water quality nationwide and was led by the researcher who had also led the NAS study. A full copy of my resume can be found in Attachment A.

My investigation of the SWAT Modeling of the Illinois River Watershed (IRW) consisted of reviewing the expert report submitted by Ms. Katherin Mendoza on behalf of the State of Oklahoma (State) on November 18, 2024. I was asked to review the model developed by Ms. Mendoza (herein referred to as the "State's model"[1]) and its application to the questions posed by the State in Ms. Mendoza's report. My effort included reviewing her SWAT model development relative to the data available on the IRW, as well as the model calibration and scenario results. Due to the size of the model (over

[1] As will later be discussed, there are differences between the SWAT model that is available publicly on the Oklahoma Hydrologic and Water Quality System (HAWQS) and the model provided in Ms. Mendoza's reliance files. Unless otherwise noted, the "State's model" or "Ms. Mendoza's model" refers to the model that was provided in Ms. Mendoza's reliance files at the time of the filing of her November 18, 2024, report.

6,000 hydrologic response units distributed over 46 subbasins across the 1 million-acre watershed) and the amount of data processed to create the files, a detailed review was not possible in the short time afforded to me to submit this report. Therefore, this review is not comprehensive, and I reserve the right to amend my findings as we continue to assess the State's model leading up to trial.

1.1 Summary of Findings

Finding 1: The results of the State's model are not usable to answer the questions posed of it because the model does not accurately represent the conditions on the watershed, lacks a proper calibration (especially during different flow regimes), and was not validated. Therefore, there is little to no confidence in its results.

Finding 2: The development and calibration of the model are flawed by the misrepresentation of wastewater treatment plant (WWTP) loads, the failure to use site-specific soil test phosphorus data to initialize the soil soluble phosphorus, and the use of unsupportable approaches to adjust the model to fit observed data.

Finding 3: The failure to use data-driven poultry litter application rates and to conduct a sensitivity analysis for this important parameter infuses the model's predictions for soluble phosphorus in the soils with an unacceptable degree of uncertainty.

Finding 4: The model simulation performed to assess the potential impact of historical poultry litter applications does not answer the question raised because it does not account for continued phosphorus loading to the land surface from other sources, such as cattle.

Finding 5: The State's attempted assessment of simulated water quality relative to the Scenic River Criterion is misguided because their approach ignores the findings of the Joint Study, which instructs that only low-flow results are to be used in assessing compliance with the Criterion

1.2 Overview of this Expert Report

This report is organized into five sections. Following this declaration and summary of findings, Section 2 provides a high-level overview of both watershed modeling on the IRW and the SWAT. Section 3 details the inconsistencies between available data and the data that was input to SWAT to develop the State's model. Section 4 discusses the calibration results of the State's model. Finally, Section 5 assesses the application of the State's model to answer the questions posed to Ms. Mendoza as part of her report.

2 Background

2.1 Modeling of the Illinois River Watershed

The IRW has been extensively studied, with multiple models having been developed since the early 2000s. Since 2015, I know of four different watershed models developed to estimate nutrient inputs within the IRW: EPA Region 6's TMDL model (Michael Baker 2023), the Mittelset et al. (2016) model, and one model developed by Oklahoma and one by Arkansas for their watershed management plans (see irwp.com [2024] for links to a recording, a summary, and presentations from the August 10, 2023, meeting where the Oklahoma and Arkansas models were discussed). All these models vary in their approaches and outputs, particularly when accounting for the contributions of poultry litter to phosphorus fluxes within the watershed (see further discussion in Section 3.2).

The two models developed as a part of Watershed Based Management Plans (WBMPs), the Illinois River Basin (IRB) model for Oklahoma and the Upper Illinois River Watershed (UIRW) model for Arkansas, use the same modeling platform (SWAT, discussed below), but differ greatly in their inputs and results. The IRB model, for example, estimates a total annual litter contribution of 126,696 tons to the watershed, while the UIRW model estimates a contribution almost an order of magnitude lower, at 16,775 tons/year. Based on the affidavit submitted by Ms. Mendoza on November 22, 2024, the IRB model serves as the foundation to the model in her report (but is not identical, as discussed in Section 2.3).

2.2 Soil and Water Assessment Tool

SWAT is a semi-distributed watershed model[2] developed by the Agricultural Research Service of United States Department of Agriculture (USDA). SWAT, which was preceded by SWRRB (Simulator for Water Resources in Rural Basins), contains equations describing numerous physical and chemical processes and requires a significant amount of data for development and calibration. The principal purpose of SWAT is to estimate runoff and pollutant loadings from rural watersheds, especially those dominated by agriculture (Williams and Arnold 1993; Arnold et al. 1998). SWAT is structured to allow simulation of land management practices, including crop growth and harvesting, fertilizer application, animal grazing and management, and other land operations that can impact sediment, nutrient, bacteria, and even pesticide loadings from the land surface (Neitsch et al. 2011). SWAT has been widely applied, with thousands of articles published since the mid-1980s describing applications of the model to environmental systems worldwide (SWAT Literature Database 2024).

[2] Watershed models are either fully distributed (meaning the equations for hydrology, sediment, and nutrients are performed on a very refined scale across the watershed), lumped (the equations are performed on average across large areas), or something in between. SWAT performs the calculations across the subbasins in a watershed at a distributed level but then lumps the results to route them through the streams. Therefore, SWAT is a combination of distributed and lumped, which is usually termed a semi-distributed model.

SWAT represents a watershed as a number of subbasins. These subbasins are further divided into hydrologic response units (HRUs), which are units of unique intersections of land use and soils. It is on the level of the HRU that most equations are solved in SWAT. The foundation behind the hydrologic simulation in SWAT is a soil water balance. This is combined with other processes on the land surface such as erosion and nutrient cycling in the soil layers (including the groundwater), including plant uptake and crop harvesting to simulate loadings from the land surface to the groundwater and surface waters in the watershed. Relevant to the IRW, SWAT allows for the simulation of cattle grazing and poultry litter application at the HRU level. All land operations in SWAT are at the HRU level and account for soil type, land cover, and HRU slope (as well as other HRU characteristics).

2.3 The State's SWAT Model Provided for this Matter

According to Ms. Mendoza's report, the State tasked Ms. Mendoza to use the model she had developed and calibrated to answer seven questions about the IRW (as well as an eighth question about Arkansas's SWAT model of the Upper IRW, which will not be directly addressed in my report). The seven questions relate to the following topics:

1. Trends in phosphorus loads and concentrations occurring in the rivers and streams of the IRW since 2010
2. The contribution of poultry waste land application, currently and historically, to current phosphorus loading in the rivers and streams of the IRW
3. The proportion of phosphorus load in the streams and rivers attributed to point sources versus non-point sources
4. The continued contribution of "legacy phosphorus" as a proportion of the phosphorus load after cessation of poultry litter application
5. The potential impact of "legacy phosphorus" on the future water quality of the IRW, if poultry litter application were to cease
6. Land management techniques that could help reduce phosphorus loading from historical and current poultry waste land application practices
7. The impact on phosphorus loads and concentrations that the land management techniques mentioned in No. 6 may have

On November 18, 2024, the State provided a USB drive that contained six compressed files comprising six model simulations (amounting to over 50 gigabytes of information when uncompressed), five of which we believe represent a simulation discussed in Ms. Mendoza's report. Given the time constraints, we have not fully reviewed every simulation provided in the reliance materials[3] to confirm that assumption, other than to identify the version that appears to match the

[3] Due to the size of the IRW and number of HRUs simulated, each model simulation contains over 40,000 input files that are read in by SWAT to simulate the watershed over the 23-year run period (including a 2-year spin up).

simulation identified as Ms. Mendoza's final calibration in her report (filename: Baseline_soil2020.7z). Four of the other compressed files appear to be model simulations used in her scenario analysis (no_litter_15filter_all_pasture_soil2020.7z, no_litter_hay_production_soil2020.7z, no_litter_same_manage_soil2010.7z, and no_litter_same_manage_soil2020.7z), and the sixth file appears to be an initial calibration of the model (Baseline_calibrated_default_soil.7z). I assumed this sixth simulation is not relevant for this work and focused my review on the simulation that appears to be consistent with the results presented in Ms. Mendoza's report as her calibration.

To the degree possible, I reviewed results from the simulations used for the scenarios. But due to the size of the model (over 6,000 HRUs distributed over 46 subbasins across the 1 million-acre watershed) and the amount of data processed to create the files, a detailed review was not possible in the short time afforded to me to submit this report. Therefore, this review is not comprehensive, and as I continue to assess the State's model leading up to trial, additional insight and information may be added to my findings.

It should be noted that the final calibration provided in Ms. Mendoza's discovery does not match the calibration files available on the Oklahoma Hydrologic and Water Quality System (HAWQS), which was referenced by Ms. Mendoza in her November 22, 2024, affidavit indicating the model used for her report was publicly available. I have not had time to perform a comprehensive comparison, but at a minimum, the HRUs that receive poultry litter application differ between the model that is downloadable from Oklahoma's HAWQS and the one provided in Ms. Mendoza's reliance materials. In particular, the HAWQS version applied litter to 244 HRUs over 33 subbasins, while the State's model applies litter to 289 HRUs over 38 subbasins. Consequently, the HAWQS IRW model could not be used directly to assess results in the State's report, particularly since the focus of most of the questions posed by the State related to the impact of poultry litter application on phosphorus loads and concentrations in the waters of the IRW. Additionally, HAWQS does not contain any of the scenario simulations provided on the USB drive that are the basis of the scenario results presented toward the end of Ms. Mendoza's report.

3 The State's SWAT Model Provided for this Matter Inaccurately Represents the Illinois River Watershed

As discussed further in Section 4, model structure and calibration are essential to having confidence in whether a model is sufficiently accurate to answer questions about source apportionment and possible impacts of future management practices. To assess model accuracy, outputs from the model simulations that predict water quality concentrations and flow rates are compared to data on water quality and flow rates collected directly from the watershed. The calibration period for the State's model was 2000 to 2020, meaning that the model needed to be developed representing the watershed over that 21-year period. My initial assessment of the model development step focused on datasets needed to initialize the model and define phosphorus sources. These inputs to the model are critical to the model's assessment of source contributions to in-stream phosphorus and the model simulations in the future scenarios. These include WWTP loads, poultry litter application rates and locations, and initial phosphorus concentrations in the soils of the areas receiving poultry litter.

3.1 Wastewater Treatment Plant Loads Are Significantly Underestimated for the Calibration Period

Point sources (i.e., WWTPs) are important contributors of phosphorus to the IRW, especially during low-flow periods (Grantz and Haggard 2023; Connolly 2024). Therefore, it is critical to accurately quantify the inputs—especially because their influence impacts calibration of the model for the low-flow period. (See further discussion in Section 4 on the importance of calibrating a watershed model to different flow regimes in order to have confidence in the output.) In the State's model, Ms. Mendoza holds the point source discharges constant over the 21-year simulation, based on what appears to be recent discharge data. She assumes that the WWTPs have been discharging since 2000 at the loads measured in 2020. Using the input files available in Ms. Mendoza's calibration simulation, I estimated that the total load she inputted is approximately 36,600 pounds per year for each year of the simulation. Although accurate for 2020, this load is incorrect and too low for earlier years (Figure 3-1). In fact, using the estimates from EPA's TMDL modeling for 2000 to 2007 (Michael Baker et al. 2015) and the data available from 2008 to 2020 downloaded from EPA's ECHO database, almost 2,000,000 pounds of total phosphorus (TP) were discharged by point sources into the streams of the IRW from 2000 to 2020. But the State's model only inputs 769,000 pounds over the same period—less than half of what actually occurred. The quality of the model predictions during low flow was negatively affected by this significant underestimate. In other words, the model is likely overestimating the historical impact of other phosphorus sources in the watershed in order to compensate for the underestimate of historical point source loadings. This is a critical flaw in the model calibration and may impact the scenarios presented in Ms. Mendoza's report.

3.2 Poultry Litter Application Simulated in the State's Model Is Unrealistic and Inconsistent with Other Information

Ms. Mendoza assumed a litter application rate of 3 tons per acre per year. She based her assumption on a litter production rate that she calculated from an estimated bird count provided by an Oklahoma Conservation Commission (OCC) employee based on a house counting methodology that is address by other defense experts. Ms. Mendoza then assumed litter production per bird per day, and she assumed that 50% of the litter produced in the IRW is applied to pastures in the watershed. This application rate and total tons of litter applied are significantly greater than other estimates used in recent modeling efforts (Table 3-1[4]). The model results presented in her Table 17 are likely sensitive to this high application rate.

In addition to using an application rate significantly higher than other estimates used in the watershed, Ms. Mendoza did not adjust the application rate based on land slope or soil test phosphorus (STP)[5]. By Ms. Mendoza's own admission on page 40 of her report, she uses SWAT's defaults for soluble phosphorus in the soils as initial values, which she indicates underestimates the true STP for the pastures receiving poultry litter based on a comparison to results presented in Storm et al. 2006[6]. Therefore, it is likely she is applying litter at rates that are not allowable under State regulations in some areas—especially since the litter is applied all at once each year. Additionally, by not considering slope, too much phosphorus is available to erode from more-steeply sloped land that typically either would not receive litter application or would receive a reduced application rate. In fact, using the input files for the State's baseline model that indicate what HRUs receive poultry litter, there are almost 4,000 acres of land with slopes greater than 8% that receive poultry litter at her full rate of application.

[4] Information on litter application is pulled from the cited reports for each study annotated in Table 3-1. Every effort was made to provide qualifiers and information so that Ms. Mendoza's assumptions can be compared. But given time constraints, not all the metrics annotated in Table 3-1 were readily available in the different reports. Therefore, values for the State's SWAT model should be compared to the relevant, qualified values from other studies, as appropriate.

[5] Oklahoma considers slope and STP when developing allowable application rates. See Table 3 of Payne and Zhang (date unknown).

[6] Ms. Mendoza references this study, but the full citation is not provided in her reliance materials.

Table 3-1
Poultry Litter Application Information Assumed for the IRW from Recent Studies

Source	IRW Bird Count	Poultry Litter Application: No. Receiving Acres	Application Rate (tons/ac/yr)	Times Per Year	Tons Applied in One Year	Application Timing	Notes
State's SWAT Model	234,557,040	42,232 (Total) 32,448 (Ark.) 9,783 (Okla.)	3	1	126,696 (Total) 97,344 (Ark.) 29,352 (Okla.)	3/1 or 4/20 depending on grazing management	Applied to pasture with no consideration for STP or slope
EPA Region 6 TMDL (Michael Baker 2015)[a]	Not used to estimate application rates	7,555 (Okla.)	0.4 to 1.9, depending on county	6	Not reported	Every other month	Applied to pasture with slopes less than 2.5%
Mittelset et al. (2016) SWAT Model[b]	40,640,000	All pasture and hay land use; assumed application rate based on STP	0.17 (average of all pasture areas)	NR	65,863	Not reported	Applied based on STP
Arkansas Watershed-based Management Plan[c,d]	Not used to estimate application rates	18,244 (Ark.) 5,100 (Okla.)	0.83 (Ark.) 0.32 (Okla.)	Unk.	16,775 (Total) 15,143 (Ark.) 1,632 (Okla.)	Unknown	Applied to pasture in litter application areas reported to Arkansas Natural Resource Division and slopes less than 6%

a. Michael Baker (2023)
b. Mittelset et al. (2016)
c. TAMU (2024)
d. Information that could not be found is reported as "Unknown" because the model documentation is under development and the information will likely be reported in that document.

3.3 Available Soil Test Phosphorus Data Were Not Used to Initialize the Model or Assess Model Performance

STP is used as a measure of phosphorus available for plant growth in soils and can be used as a surrogate for the amount of soluble phosphorus in soils. Farmers must test for STP before applying poultry litter to their land, per their nutrient management plans (Payne and Zhang, Date Unknown). These test data are available from the State agencies that employ the plan writers who develop the nutrient management plans for these farms (i.e., the Oklahoma Department of Agriculture, Food and

Forestry [ODAFF] and the Arkansas Natural Resource Commission [ANRC]) and should have been used to set initial soluble phosphorus values. Moreover, the time history of measured STP should have been compared to the calculated trends in soil soluble reactive phosphorus. An important check on model performance was not conducted.

At a minimum, Ms. Mendoza should have performed an analysis of the sensitivity of the model results to the initial values that she set. This exercise would have allowed her to assess the impact of initial value uncertainty on any observations she drew. Additionally, the calibration (i.e., the results used to calibrate the phosphorus loads [discussed further in Section 4]) may have been sensitive to these results and therefore, critically important to achieving a baseline simulation that one would be confident in. Additionally, using the time history of measured STP, Ms. Mendoza could have gotten an estimate of the rate of change (on average, across many farms) in fields that received poultry litter year after year to determine whether the increase predicted by her model was reasonable. This assessment was not performed, even though Ms. Mendoza's predicted increase in soluble phosphorus in the soils is central to many of the answers she gives to the State's questions.

4 The State's Attempt at Calibration is Flawed and the Model is Not Scientifically Acceptable

4.1 A Useful Model Requires a Rigorous Calibration

Phosphorus concentrations and mass fluxes in the rivers and streams of the IRW and in Lake Tenkiller are the net result of a complex array of physical, chemical, and biological processes that control the fate and transport of phosphorus originating from a variety of sources. The sources are dynamic, and the fate and transport processes vary on small temporal and spatial scales.

Models of phosphorus fate and transport are abstractions of reality that do not precisely describe the source dynamics and the fate and transport processes. This recognition is embodied in an axiom commonly expressed within the community of professional modelers that "All models are wrong." The second phrase in that axiom is "Some are useful."

For a model to be useful, it must include the following:

- Accepted mathematical representations of the fate and transport processes and data to parameterize those representations
- A spatial resolution needed to answer management questions
- An accurate depiction of the sources
- A demonstrated ability to replicate measured concentrations and fluxes at temporal and spatial scales important to management questions

Of particular significance to judgments of whether a model is useful to support management decisions are the data available to parameterize the fate and transport processes and the data on which to evaluate the model's predictions at the important temporal and spatial scales (e.g., across a range of flows, across seasons, and along the length of the waterbodies or watersheds being modeled). These data are critical to rigorously calibrating a model and validating its performance. For the IRW, this means the model should be calibrated for both high- and low-flow regimes because the dynamics and source mix differ between them. Such calibration provides an objective basis to judge the model's ability to reasonably represent the watershed dynamics across the range of flow conditions.

4.2 The Hydrology Calibration Applied an Unsupportable Practice to Match Observed Flows

For three of the subbasins[7] she used for calibration points, Ms. Mendoza notes that the hydrology simulation is biased low. She claims the low bias is due to "under accounting point sources" (see her report, top of page 22).

To get the model to better match the flow data for these three subbasins, she inexplicably inserts additional flow in the form of an undocumented point source to bring the base flow condition up and better match the measured U.S. Geological Service (USGS) flow data. In fact, for subbasin 8 which drains to Osage Creek, she adds 38 million gallons per day—this is equivalent to the total flow of all the WWTPs in the entire 1 million-acre watershed. In fact, 38 million gallons per day, which is just under 60 cubic feet per second (cfs), constitutes approximately 60% of the median flow in Osage Creek, meaning the model is significantly deficient in routing water to Osage Creek via its calculated groundwater flow, interflow, and perhaps some surface runoff. She adds a flow without any evidence that such a flow exists.

For subbasin 16 she adds flow despite there being no indication there is any point source present. (See her Table 3. No subbasin 16 is listed in that table, indicating there are no National Pollutant Discharge Elimination System permits in subbasin 16). I have never seen this practice to insert arbitrary flows in an attempt to force the SWAT model to reasonably replicate measured flows—and calibrating flow is foundational to assessing the other simulated variables (i.e., solids and nutrient loads). She forced in these imaginary point sources so that her simulated flow would "reflect the observed flow more accurately in these subbasins." But this step raises a concern about the accuracy of computed flows for subbasins where she does not have monitored flow to identify under- or over-predictions. Rather than add an unknown arbitrary source of water, good practice would be to investigate what is deficient in the model and attempt to correct that deficiency, which could be important beyond the three subbasins for which she had data to identify the problem. The approach she chose negatively impacts the confidence one has in the model results.

4.3 There Was No Calibration to Sediment Load at the Most Important Stations; Accurate Calibration to Sediment Load is Critical to Assessing Watershed Phosphorus Loading and Sources

In watershed modeling of nutrients, a step-wise approach is used to achieve a calibration: first calibrate flow, then sediment load, then nutrient load (like phosphorus; Arnold et al. 2012). It is important that the sediment load is calibrated before phosphorus because phosphorus tends to adsorb (i.e., bind) to sediment. Moreover, comparing computed and observed sediment loads is key

[7] Subbasin 8 (Osage Creek near Elm Springs, AR), subbasin 16 (Flint Creek at Springtown AR), and subbasin17 (Sager Creek near West Siloam Springs, OK).

to understanding how well the model represents the various watershed sources because erosion is the primary source of phosphorus during high flows. The State assertion that the phosphorus during high flows is attributable to poultry litter applied land rests, among other things, on how well the model predicts erosion and resulting sediment load.

The OCC recognized this at a public meeting where they presented a version of the State's model (Rogers et al. 2023). Slide 22 of their presentation indicates that close to 70% of the sediment and phosphorus loads occur when the flows are exceeded just 5% of the time. As an additional line of evidence, flow versus the fraction of particulate phosphorus at Tahlequah since 2000 is shown in Figure 4-1. These data indicate that above approximately 4,000 cfs, most of the phosphorus measured in the Illinois River is particulate.

Ms. Mendoza does not present in her report any comparison of her model sediment calibration to data. In fact, slide 17 of the public presentation on the State's model (Rogers et al. 2023) indicates that seven of the stations do not have LOADEST results that can be used to establish a confident calibration for sediment. Most of these stations are key monitoring locations, including Tahlequah. Showing the phosphorus load calibration absent the sediment calibration does little to provide confidence that the model reasonably represents the sediment sources because models like SWAT have a lot of parameters that can be adjusted without good data-based constraints. In other words, an under- or over-prediction in sediment load could have forced adjustments to phosphorus parameters to compensate for too much or too little sediment load such that the "true" representation of the system has been lost, thereby undermining the use of the model to answer the questions the State is posing.

4.4 Combining of Water Quality Stations That Are Not Coincident and Using Water Quality Stations That Are Not near the Downstream End of a Subbasin is Not Defensible

It is common watershed modeling practice to align subbasin outlets (the farthest downstream end of a subbasin) with gage locations. Indeed, SWAT allows subbasins to be set so that model outputs can be directly and appropriately compared to data collected at a monitoring gage. When the subbasin outlet and the gage are not coincident, it is acceptable to adjust flow by watershed area to account for the differences in watershed area between the two. (Flow is generally directly proportional to watershed size if the proration is not very large.) But water quality cannot be prorated because of inputs and in-stream processes that may occur between the monitoring location and the model outlet point. For the water quality (sediment and phosphorus) calibration, comparing a gage result to an outlet that is not at the gage introduces significant uncertainty about the accuracy of the model calibration (i.e., comparing a simulated load at the outlet of a subbasin that is at a different location than the load at the monitoring gage). For example, Figure 4-2 shows a snapshot of Ms. Mendoza's

Figure 3, zoomed into subbasin 16. For model calibration, she compared the "LOADEST load" (presented in the bar plots of Ms. Mendoza's Appendix B Figure 3) at the monitoring gage near the headwaters of the subbasin to the loads predicted at the outlet point of the subbasin (circled and labeled on my Figure 4-2) 8 miles downstream from the monitoring gage. She uses drainage area proration in an attempt to overcome the locational mismatch, but that does not account for any sediment or nutrient processes that occurred in the stream as the sediment and phosphorus flows 8 miles from the gage to the outlet. Therefore, it is inaccurate to compare phosphorus load simulated by SWAT to phosphorus load measured at this gage as evidence of reasonable "calibration."

In addition, she combined data from two water quality stations that show consistent differences (i.e., Mendoza's Figure 4 where station 7196900 is consistently approximately 20% less than the results at gage ARK0007A). As with the locational mismatch, this approach introduces significant uncertainty into the calibration.

4.5 There is Little Confidence in the SWAT Phosphorus Calibration to Be Able to Answer the State's Questions

As described on page 20 of Ms. Mendoza's report, various statistical metrics are typically used to assess model ability to replicate data. Ms. Mendoza compared average monthly results between LOADEST data-based predictions and SWAT model predictions. (Further discussion regarding LOADEST predictions is provided in Section 4.6.) Using the ranges provided in Ms. Mendoza's goodness-of-fit discussion for what is "acceptable," Table 15 indicates the majority of the goodness-of-fit measures fall outside of the "acceptable" range. This raises concerns about the use of the model to draw insights about the impact of various land use practices that are applied on a subbasin level (i.e., we need to have confidence that the model is simulating large and small spatial scales in the watershed accurately such that the impact of land use practices on phosphorus loads at a subbasin level can be assessed). For example, one-third (4 of the 12) of the basins Ms. Mendoza used for calibration have Nash-Sutcliffe measures of less than 0. (A Nash-Sutcliffe measure less than 0 indicates the mean of the measured data is a better representation of the basin than the model simulation.) Further, an additional three basins indicate a "fair" calibration for TP on a monthly basis using the percent bias as a metric (see percent bias [PBIAS] in Ms. Mendoza's Table 15 compared her Table 7). This would indicate that 7 of the 12 locations used for calibrating the model indicate "fair" or unacceptable results in representing the monthly phosphorus load in the watershed. Finally, using the third goodness-of-fit measure (KGE), none of the basins are acceptable. On page 21 of her report, Ms. Mendoza states that "...KGE was used as the primary calibration metric to evaluate model performance, with values of >0.5 considered acceptable...." But none of the results in Table 15 have a KGE value above 0.5, and only 2 of the 12 are above 0.4. This would indicate that the calibration

arrived at for this effort is unacceptable to assess the watershed conditions at large or small spatial scales.

4.6 There Is Significant Uncertainty in Calibrating the High Flows Due to the Uncertainty of the Data-Based LOADEST Model

Ms. Mendoza calibrates phosphorus loads by comparing the simulation results to loads determined using a USGS program, LOADEST,[8] which estimates daily phosphorus loads from a computed relationship between the available flow and water quality data. In essence, model results (i.e., LOADEST estimated loads) are treated as data to which the SWAT model simulation is calibrated. Recognizing that the "data-estimated" loads (i.e., the LOADEST loads) are themselves uncertain, care is typically taken when using them to calibrate the SWAT model. Commonly, high-flow loads estimated using LOADEST are uncertain because of data paucity and variability and the extrapolation of the load-flow relationship beyond the flows for which data exist. This is important to understand because these high flows carry a great deal of sediment and phosphorus in the streams and, therefore, greatly influence the load estimates.

The uncertainty at high flows is illustrated by the data at Tahlequah. The relationships between TSS and flow and TP and flow for 2013 to 2020 are presented in Figure 4-3. Both TSS and TP are low and relatively independent of flow until flow reaches approximately 1,000 cfs and then rise in an exponential fashion with increasing flow. Most river systems behave this way, with sediment transport rate being a power function of discharge (Nash 1994). As flow rises the spread of the concentrations grows, reflecting the dynamic nature of high flows, which are not well described by a simple concentration-flow relationship. Moreover, there are relatively few measurements at the highest flows. The noisy relationship of concentration and flow at high flows and the paucity of data negatively impact the accuracy of the loads estimated by LOADEST. In fact, these problems resulted in complete failure of the LOADEST model as a tool to estimate solids loads through several major tributaries and the Illinois River. The absence of data-based solids loads estimates at important locations and the high uncertainty of high-flow phosphorus load estimates compromise assessments of the model predictions.

4.7 The Model Was Not Validated

Watershed models are typically calibrated to one dataset and validated against another dataset (Arnold et al. 2012). Arnold et al. (2012), whose authors include the developers of SWAT, define appropriate methods for calibration and validation of SWAT models, noting that "[m]odel validation is the process of demonstrating that a given site-specific model is capable of making sufficiently

[8] The summary statistics for LOADEST presented in Ms. Mendoza's Table 6 are for predictions of concentration, not load. For many of the monitoring locations, the LOADEST regression used to estimate load (to which the SWAT model is calibrated) is deemed as unusable by the metrics defined by the LOADEST developers. But Ms. Mendoza does not annotate this limitation in her report.

accurate simulations...." Based on a review of the literature, they conclude that "[m]ost reported SWAT studies contain both calibration and validation...."

Contrary to the approach described in Arnold et al. (2012), Ms. Mendoza elected to disregard validating the model and instead used all available data to calibrate the model. Because the purpose of model validation is to independently assess model performance (Arnold et al. 2012), the lack of validation severely limits our ability to understand model performance. The model performance, with respect to the calibration data, is reported in the model output files. But without a validation step, the model performance with respect to any other dataset is unknown. It is very common for model performance with respect to the validation dataset to be poorer than its performance to the calibration dataset. As a result, the performance of the State's model when used for scenarios such as land management techniques is unknown but can be expected to be poorer than the stated calibration metrics.

5 The Scenario Results Are Flawed

5.1 There Is Little Confidence in the Model's Prediction of Soluble Phosphorus in the IRW's Soils Over Time

For many of the answers Ms. Mendoza provides to the questions posed by the State, she uses average soluble soil phosphorus concentration predicted by her model to support her conclusions. There is little confidence in these results for the following reasons:

1. As previously discussed, there are serious flaws and weaknesses in the model development and calibration, which lead to little to no confidence in the model predictions.
2. The litter application rate assumed by Ms. Mendoza is 4 to 10 times higher than rates used for EPA's and Arkansas's modeling efforts. Given the differences in simulated soluble phosphorus concentrations in the subbasins that received poultry litter versus those that did not (see Ms. Mendoza's Figure 21), it is likely that the model predictions are sensitive to the application rate. In fact, Ms. Mendoza knew her application rate was much higher than that used in the other models (TAMU 2023) yet did not appear to have investigated the sensitivity of her results to that rate. Lacking this understanding, one has to skeptically view the predictions provided by the model.
3. Some answers she provides may have been "pre-ordained" by the assumed high litter application rate. For example, the rise in soil soluble reactive phosphorus over time shown in her Figure 20 is so steep because the high application rate forces that slope. Additionally, as already mentioned in Section 3.3., the slope of this line could have been checked for reasonableness, given available STP data, but it was not.
4. As discussed in Section 3.3, without a sensitivity analysis to understand the impact of having initial soil soluble phosphorus concentrations that differ significantly from real world values, it is not clear one can trust the model predictions of these concentrations, even on a relative basis.

5.2 The Assessment of Legacy Phosphorus is Flawed

One of the questions posed by the State to Ms. Mendoza relates to "legacy phosphorus" which she defines as "the amount of phosphorus that is left in the soil at the end of the year." Ms. Mendoza addressed this question by providing predicted soluble phosphorus concentrations over time for the 21-year simulation, with the cessation of poultry litter application in 2010. The presumption is that the trends in soluble phosphorus post-cessation of litter application result from previously applied litter. The flaw with this approach is that the trend reflects the fact that the model continues to apply phosphorus to the land surface (i.e., hogs, cattle, and other fertilizers). Therefore, this scenario does not answer any questions about any impacts of "historic poultry waste land application" on future conditions.

5.3 The Approach Used to Compare the Model Concentrations to the Scenic River Criteria Ignores the Findings of the Joint Study

In her answer to Question 1, Ms. Mendoza presents her baseline calibration results as annual average concentrations for 2010 to 2020 and compares those to Oklahoma's scenic river criterion of 0.037 milligram per lite (mg/L). Even if there were confidence in the model results, this comparison is flawed because it ignores the findings of the Joint Study (King et al. 2016) that concluded the assessment of the Illinois River should be performed during low flow. The State further clarified the appropriate way to assess the water quality in the IRW in 2020 with guidance on how to interpret the Joint Study's findings (OWRB 2020). This guidance is consistent with assessing the waterbodies during low-flow conditions. But in Ms. Mendoza's Figures 12 through 17, the average shown will be heavily influenced by the concentrations predicted during high flow, even though the OWRB guidance is clear that those values should not be included when comparing to the 0.037 mg/L criterion.

6 References

Arnold, J. G., R. Srinivason, R. R. Muttiah and J. R. Williams, 1998. "Large Area Hydrologic Modeling and Assessment Part I: Model Development." *Journal of the American Water Resources Association* 34(1): 73-89.

Arnold, J.G., D.N. Moriasi, P.W. Gassman, K.C. Abbaspour, M.J. White, R. Srinivasan, C. Santhi, R.D. Harmel, A. van Griensven, M.W. Van Liew, N. Kannan, and M.K. Jha, 2012. "SWAT: Model Use, Calibration, and Validation." *Transactions of the ASABE* 55(4):1491–1508.

Connolly, J., 2024. *Expert Report on Water Quality in the Illinois River Watershed.* In the matter of: State of Oklahoma v. Tyson Foods, Inc. November 2024.

Grantz, E.M. and B.E. Haggard, 2023. *Constituent Loads and Trends in the Upper Illinois Watershed: A Nonpoint Source Management Program Priority Watershed.* Prepared for the Arkansas Water Resources Center. MSC394. February 2023.

irwp.org, 2024. "The Watershed Management Plans for the Illinois River in Oklahoma and Arkansas Are Getting an Update." Accessed November 27, 2024. Available at: https://www.irwp.org/watershed-management-plan.

King, R., B. Haggard, D. Smithee, R. Benefield, S. Chard, M. Matlock, and S. Phillips, 2016. *Final Report to Governors from The Joint Study Committee and Scientific Professionals.* December 19, 2016.

Michael Baker (Michael Baker International), 2023. *Illinois River Watershed HSFP Model Updates.* Technical Support Document. Prepared for USEPA Region 6. July 18, 2023.

Michael Baker, Aqua Terra, and Dynamic Solutions (Michael Baker Jr., Inc., Aqua Terra, Consultants, and Dynamic Solutions, LLC), 2015. *Setup, Calibration, and Validation for Illinois River Watershed Nutrient Model and Tenkiller Ferry EFDC Water Quality Model.* Final. Prepared for USEPA Region 6. August 7, 2015.

Mittelstet, A.R., D.E. Storm, and M.J. White, 2016. "Using SWAT to Enhance Watershed-Based Plans to Meet Numeric Water Quality Standards." *Biological Systems Engineering: Papers and Publications.* 386. Available at: https://digitalcommons.unl.edu/biosysengfacpub/386/.

Nash, D.B., 1994. "Effective Sediment-Transporting Discharge from Magnitude-Frequency Analysis." *The Journal of Geology* 102:79–95.

Neitsch, S.L., J.G. Arnold, J.R. Kiniry, and J.R. Williams, 2011. *Soil and Water Assessment Tool Theoretical Documentation Version 2009.* Prepared for Texas A&M University System. Texas Water Resources Institute Technical Report No. 406. September 2011.

OWRB (Oklahoma Water Resources Board), 2020. *Illinois River Watershed Total Phosphorus: Criterion Revision.* Staff Report. December 1, 2020.

Payne, J. and H. Zhang, date unknown. *Poultry Litter Nutrient Management: A Guide for Producers and Applicators.* Prepared for Oklahoma Cooperative Extension Services.

Rogers, B., G. Kloxin, S. Philips, R. Srinivasan, K. Mendoza, and S. Moore, 2023. *Illinois River Basin (IRB) Flow and Water Quality.* September 25, 2023.

SWAT Literature Database, 2024. Available at: https://litdb.swat.tamu.edu.

TAMU (Texas A&M AgriLife Research), 2024. *Comparison of Inputs and Outputs Between the UIRW and IRB Models.* November 15, 2024.

Williams, J.R. and J.G. Arnold, 1993. "A System of Hydrologic Models." *Proceedings of the Federal Interagency Workshop on Hydraulic Modeling Demands for the 90's.* Fort Collins, Colorado, June 6–9. U.S. Geological Survey. Water-Resources Investigations Report 93-4018, pp. 4-8 – 4-15.

Figures

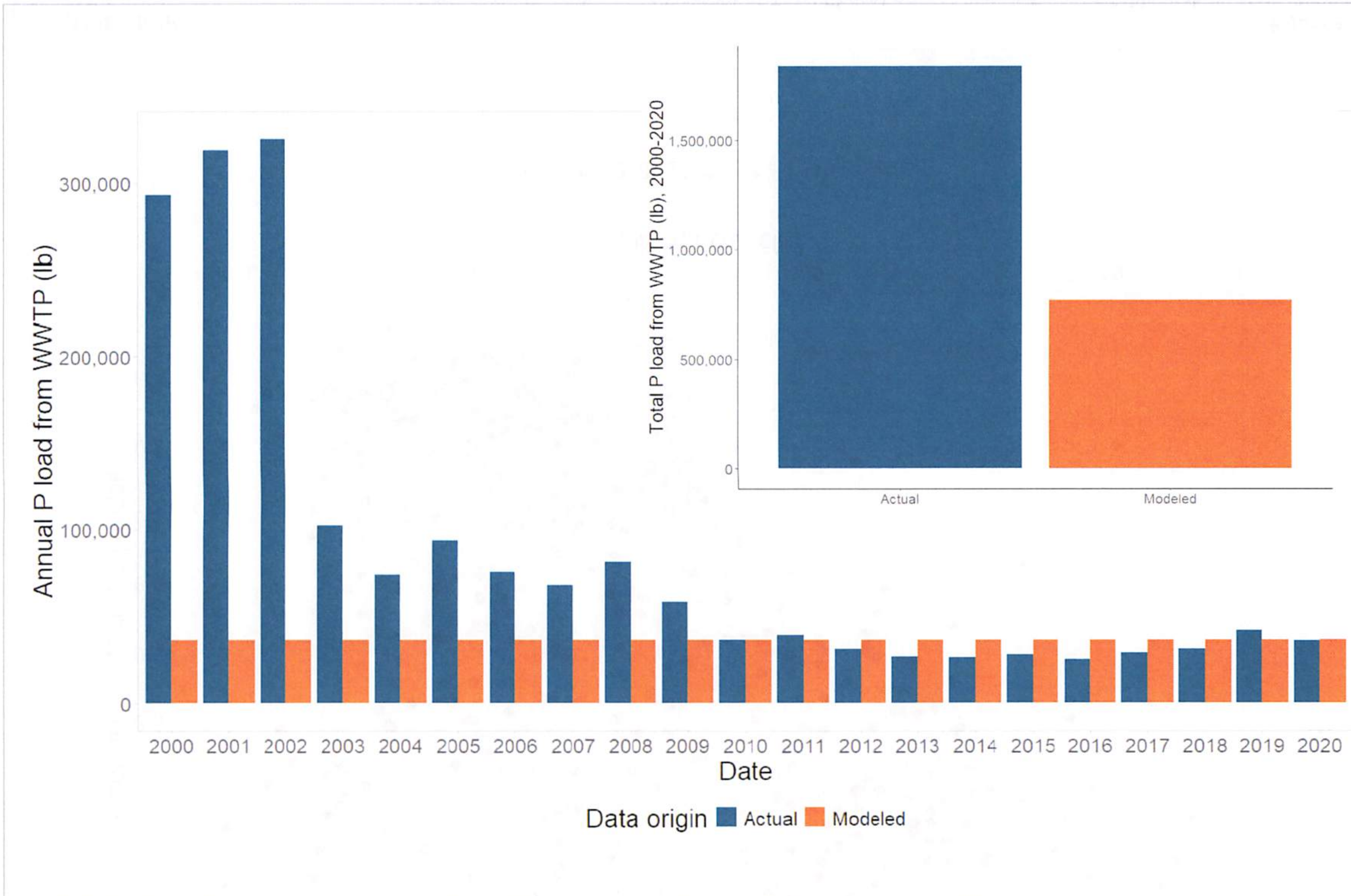
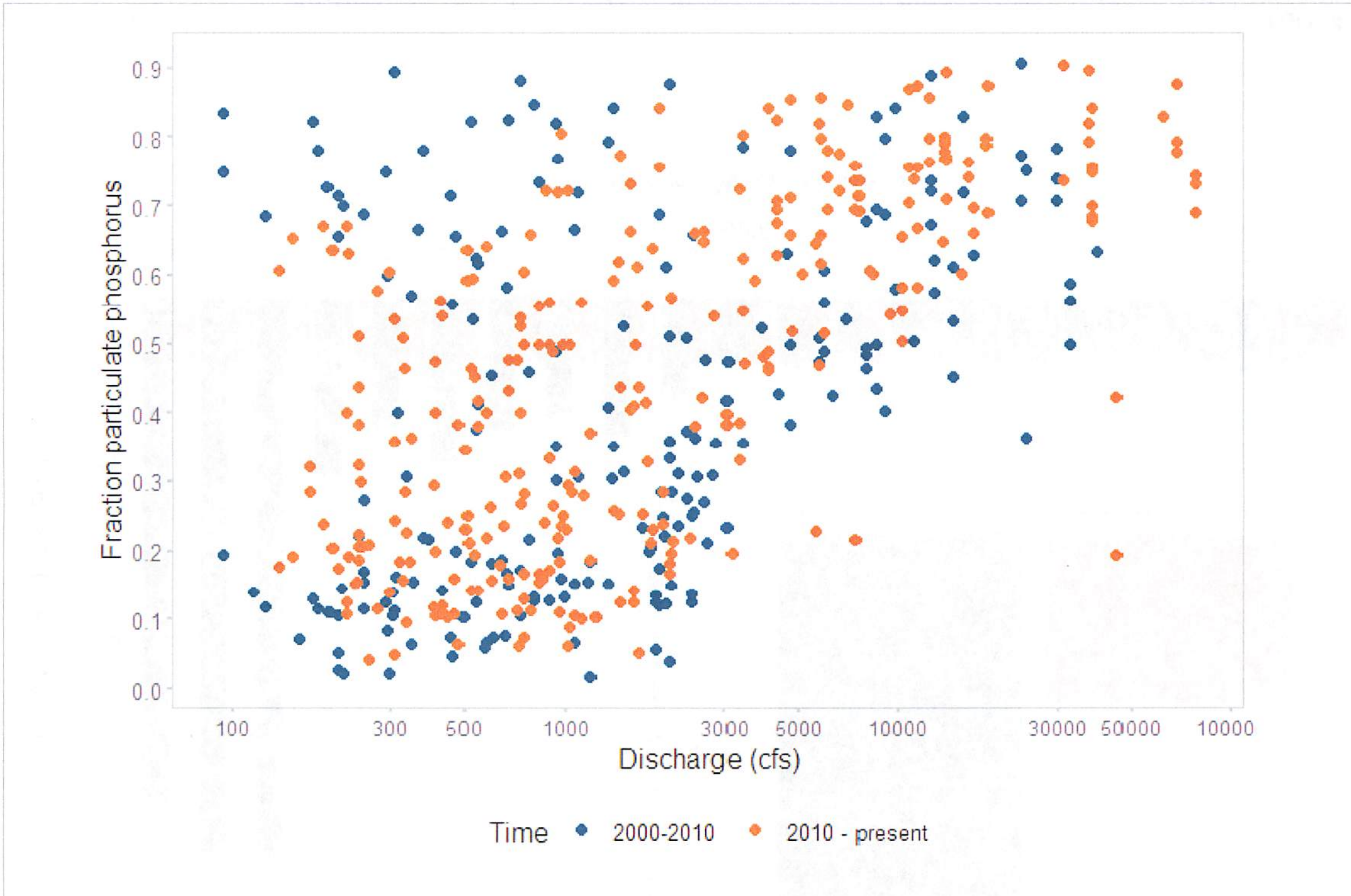


Figure 3-1
Total Watershed Phosphorus Load from Wastewater Treatment, SWAT Model Compared to Reported Release Data

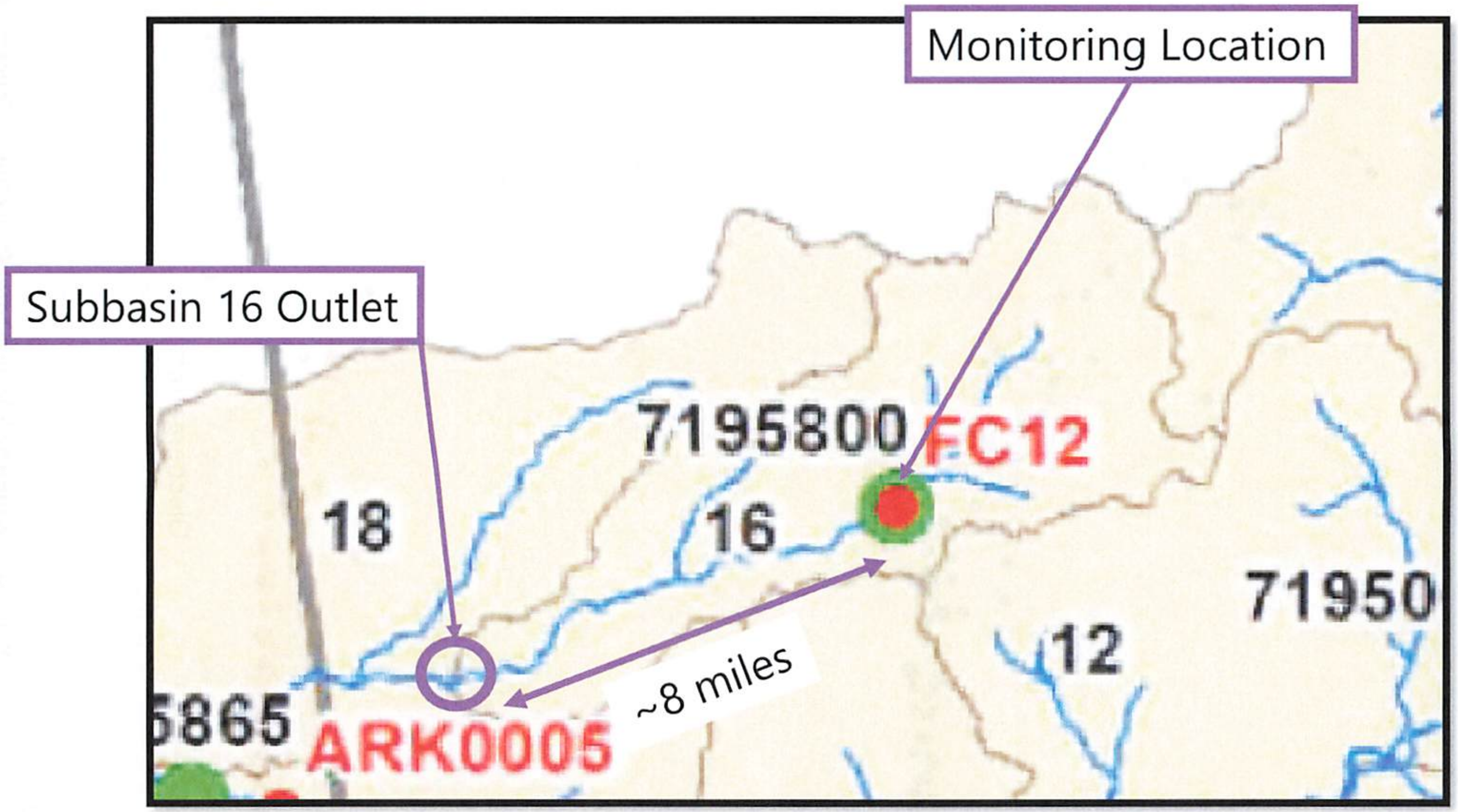


Filepath \\WCL-FS1\Saratoga\Projects\McDanielAcord\Illinois River Poultry NRD\Documents\AQ Documents\202411 Benaman Rebuttal Report\Figures

ANCHOR QEA

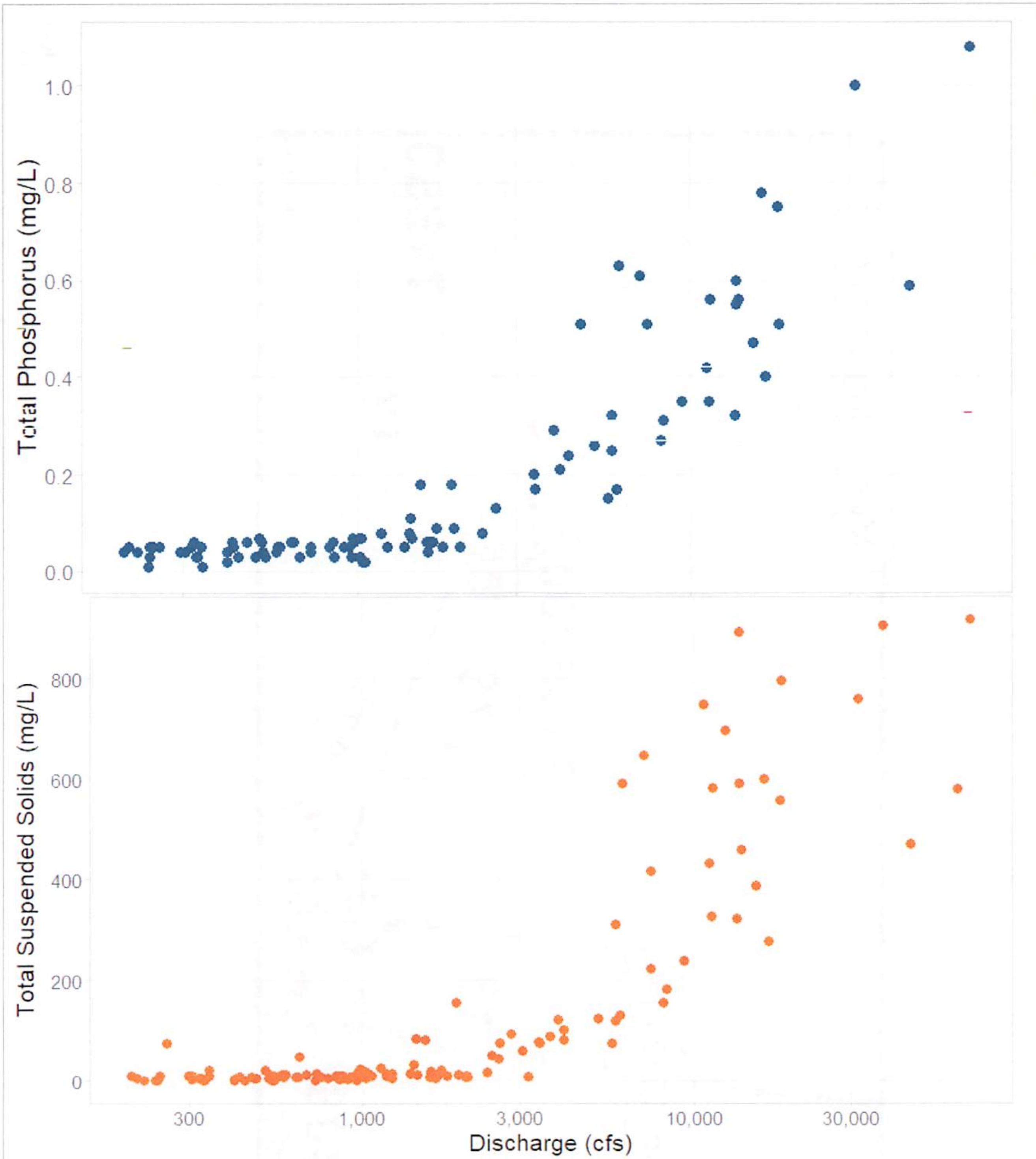
Figure 4-1

Particulate Phosphorus as Fraction of Total Phosphorus at Illinois River at Tahlequah by Flow, 2000 to Present



Filepath: \\WCL-FS1\Saratoga\Projects\McDanielAcord\Illinois River Poultry NRD\Documents\AQ Documents\202411 Benaman Rebuttal Report\Figures

Figure 4-2
Zoom In of Ms. Mendoza's Figure 3 Showing Subbasin 16

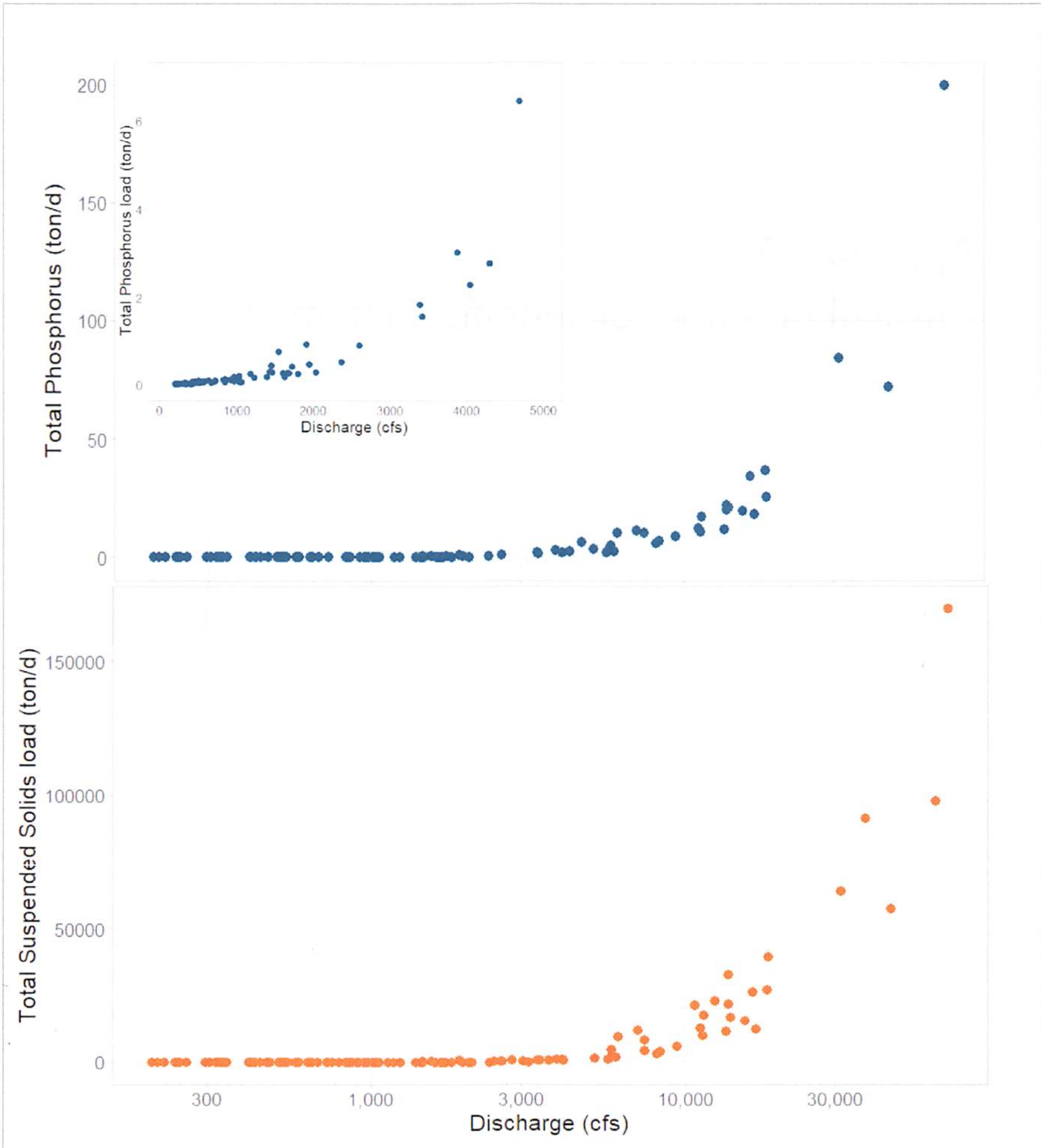


Filepath: \\WCL-FS1\Saratoga\Projects\McDanielAcord\Illinois River Poultry NRD\Documents\AQ Documents\202411 Benaman Rebuttal Report\Figures

ANCHOR QEA

Figure 4-3
Total Suspended Solids and Total Phosphorus Concentration versus Flow, Illinois River at Tahlequah, 2013 to 2020

Rebuttal Report for State's SWAT Model
Illinois River Watershed Joint Defense Group



Filepath: \\WCL-FS1\Saratoga\Projects\McDanielAcord\Illinois River Poultry NRD\Documents\AQ Documents\202411 Benaman Rebuttal Report\Figures

Figure 4-4
Total Suspended Solids and Total Phosphorus Load versus Flow, Illinois River at Tahlequah, 2013 to 2020

Rebuttal Report for State's SWAT Model
Illinois River Watershed Joint Defense Group

Appendix A
Curriculum Vitae for Jennifer Benaman

Jennifer Benaman, Ph.D.

Principal

An expert in her field, Dr. Benaman's body of work has focused on watershed and water quality modeling, adaptive management, contaminated sediments, and uncertainty analysis. Her work has sought to quantify uncertainty so that meaningful and practical methods can be applied to address uncertainty when applying models to watershed/nutrient management, Total Maximum Daily Loads (TMDLs), and environmental remediation. Dr. Benaman has experience with sampling and analysis of chemicals for remedial investigations and site assessments, model development, watershed modeling and management, the fate of toxic chemicals in the environment, and eutrophication with nutrient loading analysis.

Dr. Benaman has worked extensively with numerous water quality and watershed models, including SWAT, HSPF, WASP, GWLF, Qual2E and other EPA-approved models. For her dissertation, Dr. Benaman conducted research on the application of SWAT to a rural watershed in Upstate New York to understand the impacts of agricultural practices on water quality of a reservoir that serves as a water source for New York City, including the uncertainty of the results for implementing management decisions. Since obtaining her Ph.D., she has led numerous projects that have applied SWAT to other systems, including a combined watershed/water quality modeling system for series of in-river reservoirs in central Texas.

Another focus for Dr. Benaman has been assessing TMDL development, including how modeling and uncertainty impact management decisions for TMDLs. She has been involved in the development of TMDLs and critically reviewed TMDLs developed by others, including the modeling approaches applied and their proposed load reduction targets. She also served on a national expert panel whose goal was to understand the potential use of adaptive management in watershed management and TMDLs. This panel was a follow up study to the National Academies' study of the impact of TMDL implementation on the management of water quality in the United States.

Education

Ph.D., Civil and Environmental Engineering, Cornell University, 2003

M.S., Civil Engineering, University of Texas, Austin, 1996

B.S., Civil Engineering, Florida Institute of Technology, 1994

Memberships

EPA Science Advisory Board

American Society of Civil Engineers

Water Environment Federation

Work History

Anchor QEA, Principal, 2005 to pres.

Anchor QEA, Project Manager, 2002 to 2004

Cornell Univ., Department of Civil and Environmental Engineering, U.S. Environmental Protection Agency (EPA) STAR Fellow, 1999 to 2002

Univ. of Texas at Austin, Adjunct Faculty, Dept. of Civil Engineering, 2003 to 2004

Anchor QEA, Professional/Senior Professional, 1998 to 2002

HydroQual, Inc., Graduate Engineer II, 1996 to 1998

Univ. of Texas at Austin, Dept. of Civil Engineering, National Science Foundation Fellow, 1994 to 1996

Brevard County, Florida, Surface Water Improvement Division; Graduate Engineer, 1994

E.A. Thaner and Associates, Intern, 1993

Univ. of Hawaii at Manoa, School of Ocean and Earth Science and Technology; Research Assistant, 1992

Project Experience

Development of a 9-Element Plan for the Seneca and Keuka Lakes *New York State* *Geneva, New York*	Dr. Benaman was a technical advisor for the development and implementation of a watershed model (SWAT) for the Keuka and Seneca Lakes watersheds for the development of a 9 Element Plan (i.e., watershed management plan). The work included interaction with the state and other watershed stakeholders to develop the model and evaluate nutrient loads to the lakes from the watershed.
Development of a Watershed/Water Quality Model for the Cannonsville Reservoir System *Delaware County* *Delaware County, New York*	Dr. Benaman served as primary developer of a watershed model for a New York City water supply reservoir basin using SWAT. Her work included data analysis, model input development, calibration, validation, sensitivity and uncertainty analysis. This project also entailed public meetings with stakeholders, politicians, and local scientists. This project was prompted by the desire of NYC to protect the headwaters of its water supply through land use management.
Bosque River Nutrient Evaluation *City of Waco* *Waco, TX*	Dr. Benaman was the Principal in Charge for an analysis of phosphorus in the Bosque River. She oversaw the team in their evaluation of TMDL targets, review of assessment and attainment of standards, and quantification of stormwater loads. She also provided guidance and support to the team for their meetings with TCEQ and stakeholders to explain the data and address concerns.
Illinois River Watershed, Water Quality and Watershed Assessment *Poultry Industry Joint Defense Group* *Eastern Oklahoma*	Dr. Benaman served as coordinating expert for over 11 experts in evaluating the potential impacts of poultry litter on the water quality to assess eutrophication within the Illinois River Watershed in Oklahoma. She aided in the coordination of other experts' reports, as well as coordination of analyses and database management. Dr. Benaman also co-led the development of Anchor QEA's expert report which analyzed the water quality of the rivers within the watershed, as well as Lake Tenkiller, the receiving waterbody for the basin. She supported Anchor QEA's expert through deposition and testimony.
Fort Cobb Nutrient TMDL Review *Oklahoma Farm Bureau* *Fort Cobb, Oklahoma*	Dr. Benaman managed the critical review of a nutrient TMDL developed on Fort Cobb Reservoir by the state of Oklahoma. The review consisted of evaluating the application of SWAT and EFDC to the watershed, the development of the TMDL and the proposed implementation. Final comments were submitted to the Oklahoma Department of Environmental Quality (DEQ) on behalf of the Oklahoma Farm Bureau. Her work also included attending public meetings and interacting with the Oklahoma DEQ.
North Canadian River Bacteria TMDL Review *Oklahoma Farm Bureau* *Central Oklahoma*	Dr. Benaman managed the critical review of a bacteria TMDL developed on North Canadian River by the state of Oklahoma. The review consisted of evaluation of the TMDL development, source assessment, and proposed implementation. Final comments were submitted to the Oklahoma Department of Environmental Quality (DEQ) on behalf of the Oklahoma Farm Bureau.

LCRA Colorado River Modeling System Phases 3 and 4 – Lake Buchanan, Lake LBJ, Inks Lake, and Lake Marble Falls Project *Lower Colorado River Authority* *Austin, Texas*	Dr. Benaman served as a technical advisor for the development, calibration, and application of combined watershed (SWAT)/water quality (CE-Qual-W2) models on four lakes with the Lower Colorado River Authority's service area. These models are used for management decisions related to urban development and the potential increase of point source nutrient inputs to the lakes.
LCRA Colorado River Modeling System Phase 2 – Lake Travis Project *Lower Colorado River Authority* *Lake Travis, Texas*	Dr. Benaman led the consultant team that developed a watershed (SWAT) and receiving water quality (CE-Qual-W2) model of Lake Travis to understand nutrient loadings to the lake and their potential future impact. Work included assessing current data and literature, model development, calibration, uncertainty, and application for future scenarios.
Stone Dam Creek Nitrate/Ammonia TMDL *Parsons/USEPA Region 6* *Arkansas*	Dr. Benaman served as project manager for the development of a nitrate and ammonia TMDL for Stone Dam Creek in Arkansas. TMDL development included data acquisition, analysis, source assessment, and load allocations. Her duties also included responding to comments from the EPA and the public concerning the TMDL.
State of Texas TMDL Assessment *Texas Natural Resource Conservation Commission, University of Texas at Austin* *Texas*	Dr. Benaman performed an independent assessment of existing water quality and watershed models in relation to their application to development of Texas TMDLs. This task entailed evaluating watershed models, as well as in-stream water quality models to determine their appropriateness to the Texas environment.
TMDL Adaptive Implementation Expert Panel *Center for the Analysis and Prediction of River Basin Environmental Systems, Duke University*	Dr. Benaman participated on a panel of expert scientists and engineers to investigate the use of adaptive implementation in the TMDL process. Her work included meetings with the panel and other professionals performing TMDLs across the country. The final product was a monograph released for public use and reviewed by the U.S. EPA. This monograph was meant as a follow-up document to the 2001 National Academies' Report on TMDLs.
Water Quality Impacts of a Parking Lot Expansion, Expert Witness *Hope in the City Church* *Austin, Texas*	Dr. Benaman provided expert witness testimony on behalf of Hope in the City Church regarding the water quality impacts of the Church's proposed parking lot expansion on a nearby receiving creek. Her testimony included an expert report investigating non-point source loads from the parking lot expansion and impact assessment of the receiving stream, and rebuttal report.
Development of a Watershed/Water Quality Model for North Sandy Pond *Oswego County* *Oswego County, New York*	Dr. Benaman managed the development of watershed/water quality models for North Sandy Pond, off Lake Ontario. This project included the implementation and customization of EPA's BASINS Program to simulate the impact of nutrient loadings to the lake.

LCRA Colorado River Modeling System Phase 1 – Lake Travis *Lower Colorado River Authority* *Lake Travis, Texas*	Dr. Benaman led the consultant team that served as technical advisors to the LCRA for the development of a watershed and receiving water quality model of Lake Travis, Texas. Her work included assessing current data and literature, model development, calibration, uncertainty, and application.
Greater Harbor Waters Toxics TMDL Technical Expert *Ports of Los Angeles and Long Beach* *Los Angeles and Long Beach, California*	Dr. Benaman provided technical support for the development and review of a contaminated sediment TMDL for the Ports of Long Beach and Los Angeles. Her work included strategic discussions with the Ports management, review of the TMDL and discussions of technical strengths and weaknesses in the TMDL approach.
San Francisco Bay PCB TMDL *General Electric Company* *San Francisco, California*	Dr. Benaman was involved in a comprehensive review of a PCB TMDL and related Basin Plan Amendment developed by the San Francisco Bay Regional Water Quality Control Board. The review included analysis of the system, including understanding of the PCB contamination in sediment, water, and fish; review of the Bay's food web; estimation of external loadings to the San Francisco Bay; and assessment of the modeling used for the TMDL development.
TMDL Workshops *Various clients* *Various locations*	Dr. Benaman developed and implemented workshops for different stakeholder groups to educate industry and agency professionals on the TMDL process. The focus of the workshops was primarily on the development of TMDLs, their implementation, and their impact on the various stakeholders involved in the process. The content focused on outlining guidance documents, reviewing past TMDL developments, and discussing the policies of the current procedures.
Stillman Pond Watershed Assessment *General Electric Company* *Bridgeport, Connecticut*	Dr. Benaman oversaw the implementation of a storm event monitoring program to evaluate non-point source loadings to Stillman Pond, Bridgeport, Connecticut. Work has including monitoring plan development and will eventually include data analysis to assess loadings.
LCRA-SAWS Colorado River and Off-stream Reservoir Water Quality Project *Lower Colorado River Authority (LCRA) and San Antonio Water System (SAWS)* *Austin, Texas*	Dr. Benaman managed the development of water quality and watershed models on the Colorado River, downstream of Austin, Texas. These models were developed to understand the impacts of a proposed water transfer project from the Colorado River to San Antonio, Texas. Her work included data acquisition and analysis; field sampling; and model development, calibration, and projections. This study was part of a larger project that coordinated information from 11 different environmental studies and included outreach efforts, including public meetings and an expert panel review.
LCRA-SAWS Matagorda Bay Health Evaluation Project *LCRA, SAWS, and Espey Consultants* *Austin, Texas*	Dr. Benaman was on a multi-disciplinary team that studied the impact of a proposed water diversion from the Colorado River Basin to the San Antonio Basin. The study entailed hydrodynamic/salinity modeling, nutrient modeling, habitat assessments and modeling, and bio-statistical analysis.

LCRA-SAWS South Texas Project Water Quality Study *Lower Colorado River Authority and San Antonio Water System* *South Texas*	Dr. Benaman managed the analysis of the impact of a transferring water from Lower Colorado River to South Texas Project Nuclear Plant for cooling water. The analysis focused on measuring the quantity and quality (salinity) of water available in a tidally influenced reach of the river. The project entailed coordination among LCRA, SAWS, and South Texas Project (STP), as well as monitoring oversight, extensive data compilation and analysis, statistical modeling, and deterministic modeling.
LCRA-SAWS Water Project Study Plan Development *San Antonio Water System, Lower Colorado River Authority, CH2M Hill-Austin* *Austin, Texas*	Dr. Benaman was a technical contributor on the development of a 7-year study plan to evaluate the projected impacts and benefits of the LCRA-SAWS Water Project, with respect to the health and productivity of Matagorda Bay and water quality characteristics of the lower Colorado River. The river is located downstream of Austin, Texas.
Jamaica Bay Eutrophication Study *New York City Department of Environmental Protection* *New York, New York*	Dr. Benaman assisted with the development of a mathematical model to study eutrophication in an urbanized bay of New York City. She also assisted on a sediment model of the bay to aid in the calibration of the project's larger sediment/water model.
Brevard County, Various Projects *Surface Water Improvement Division of Brevard County* *Brevard County, Florida*	Dr. Benaman worked for a county department focused on controlling non-point source pollution from urban and open areas to the Indian River Lagoon in east Florida. She reviewed retrofit designs for urban BMPs, attended public meetings to educate homeowners on non-point source controls, and assessed non-point source pollution potential in different watersheds based on land use and drainage.
Understanding the Fate and Transport of PFAS in a Midwest River *Confidential Client*	Dr. Benaman led the support an expert witness analyzing the fate, transport, and bioaccumulation of perfluorooctane sulfonate (PFOS) in a Midwest river. Work included quantifying sources, developing sampling programs, analyzing the data, and assessing PFOS fate and bioaccumulation in the aquatic food web. She led analyses of Health Advisories in relation to drinking water wells and the potential migration and co-mingling of PFAS in the groundwater from various landfills in the region.
Assessing PFAS Fate and Sources *Confidential Client*	Dr. Benaman is leading a team to support counsel for a multi-district litigation related to potential PFAS contamination of drinking water from AFFF application. The work includes reviewing technical documents to characterize sites, reviewing regulations in relevant states, determining the fate and transport of PFAS on the site given watershed and geological characteristics, and assessing possible PFAS sources to the receptors.

PFAS Investigations in North Alabama *Confidential Client*	Dr. Benaman was technical advisor for a study of 10 sites to determine if landfills were located on the sites, and if so, to establish the timeframe of disposal of waste possibly containing PFAS. Soil, sediment, seep water, and/or surface water were collected at four of the sites. Dr. Benaman oversaw the development and implementation of the sampling plans She also directed the analysis of initial remedial action studies at one of the sites.
Environmental Regulatory Support for PFAS *Confidential Client*	Dr. Benaman led a team that researched current and pending regulations/guidance and their possible impact on sites throughout the United States and globally. The reviews included proposed guidance and regulations in Europe, Australia, Canada, and various states. She also contributed to comments on these documents, reviewed Unregulated Contaminant Monitoring Rule 3 (UCMR3) data, recommended strategic direction for the client, and distilled technical concepts into text for non-technical audiences.
Understanding of PFOA Sources and Migration for an Industrial Site in Europe *Confidential Client*	Dr. Benaman led a team performing a peer review of work associated with the migration of PFASs from an industrial site in Europe. Work included assessing possible sources, developing a conceptual site model, and reviewing the existing analyses and models for the site, including groundwater transport and vadose zone models.
PFAS Evaluations at an Industrial Site *Confidential Client*	Dr. Benaman led a team in the evaluation of management options for sludge containing PFASs and the disposition of PFAS in sludge applied to agricultural fields. She also assessed sources of PFAS from the site and developed a conceptual site model for PFAS fate and transport in surface water and groundwater.
Lower Passaic River Study Area *Cooperating Parties Group* *Newark, New Jersey*	Dr. Benaman co-led a team that supported the development of a Feasibility Study for the Interim Remedy for 2,3,7,8-TCDD and PCBs on Upper 9 Miles on the Lower Passaic River. Work included supporting the FS content developing, including interpreting model results, interacting with agencies and client groups during the FS development, and supporting the coordination of monitoring to assess the current conditions on the Upper 9 Miles.
Remedy Effectiveness on the Upper Hudson River *General Electric Company* *Fort Edward, New York*	Dr. Benaman is leading a team that is collecting fish, water, and sediment data on the Upper Hudson River PCB Superfund site to assess the effectiveness of the remedy implemented from 2009 – 2016. Work has included overseeing data collection and analysis, as well as conversations with EPA on interpretation of results.
Lower Hudson River Studies *General Electric Company* *New York*	Dr. Benaman is leading a team that is collecting fish, water, and sediment data on the Lower Hudson River to assess PCB levels and potentially levels of other constituents in these media on the 150 miles of river between Albany and New York City.

In-River Monitoring During Deconstruction of a Shoreline Powerhouse *General Electric Company* *Fort Edward, New York*	Dr. Benaman is involved with a monitoring program put in place to ensure the deconstruction of a Powerhouse which sits on the shoreline of the Upper Hudson River does not inadvertently release landside, buried PCBs to the River. Work has included developing a monitoring plan, including response actions if increases in PCBs are found downstream of the deconstruction site. The Powerhouse sits adjacent to GE's historical PCB land side operations and care is needed to be sure that NAPL pools that are currently controlled with a source containment system are not disturbed.
Evaluation of the Bristow-Wilcox Superfund Site *Confidential Client* *Bristow, Oklahoma*	Dr. Benaman oversaw the review of data and reports to assess the source of contamination of measured hydrocarbons and other chemicals at the Bristow-Wilcox Superfund site in Bristow, Oklahoma. Her work involved review of multiple reports, including remedial investigations and sampling summaries to determine the occurrence and potential sources of various chemicals associated with petroleum activities.
Support for PCB Forensic Analysis *Thomas and Betts, Inc.* *Boston, Massachusetts*	Dr. Benaman supported the development of an expert report assessing the sources of PCBs to a small brook in eastern Massachusetts. Her work included coordination with the team, as well as quality review of the PCB forensic analysis and report development.
Investigation of Jet Fuel Releases to Boston Harbor *MassPort and SwissPort* *Boston, Massachusetts*	Dr. Benaman supported the development of an expert report assessing the release of jet fuel to Boston Harbor and its possible impact on the water quality and associated clam beds. Expert witness report was submitted.
Understanding the Impact of PCB Concentration During Dredging on the Hudson River *General Electric Company* *Fort Edward, New York*	Dr. Benaman supported the development of an expert report for litigation to understand the impact of dredging on PCB concentrations in the Hudson River near a drinking water intake. Support included preparation of interrogatories and deposition.
Evaluation of the Hudson River Phase 1 Dredging Program *General Electric Company* *Fort Edward, New York*	Dr. Benaman led an evaluation of the residuals data collected during the Phase 1 dredging on the Hudson River for incorporation into the Phase 1 Evaluation Report for review by an external panel of Peer Reviewers. Her duties also included coordination of the final production of the full report, which included evaluations of resuspension and productivity, as well as communication of issues and results to the Peer Review panel. She also was a key member of GE's Phase 2 negotiation team, providing support in the area of residuals and resuspension analyses.
Upper Hudson River Modeling System *General Electric Company* *Fort Edward, New York*	Dr. Benaman coordinated the development of a linked modeling system that simulated hydrodynamics, sediment transport, PCB fate and transport, and bioaccumulation models.

Management of the Hudson River Residuals Analysis Program *General Electric Company* *Fort Edward, New York*	For the Phase 1 dredging program on the Hudson, Dr. Benaman led the development and application of the Residuals Analysis System, which was a GIS-based decision support system to aid in the determination of how dredging should proceed on the river, in light of the project's residual standards. The Residual Analysis System was a complex analysis and map-making tool that allowed quick processing of residual sediment data in order to set re-dredge prisms and determine "next steps" required within each dredging "unit" to keep the dredging progressing through the season.
Support of Remedial Design Effort on the Hudson River *General Electric Company* *Fort Edward, New York*	Dr. Benaman supported General Electric and other consulting firms with analysis for the design of the dredging program for the upper Hudson River PCB sediments. Her activities included management of a project-wide GIS database, including updating and releasing the database to multiple users; support to design consultants on dredge prism development and analyses; and development of a proposal for the implementation of a web-based GIS interface of dredging program information and progress.
Delineation of Contaminated Sediments in the Hudson River *General Electric Company* *Fort Edward, New York*	Dr. Benaman managed efforts to delineate the dredging areas for PCB remediation in the Hudson River. Those efforts included managing the analysis of more than 8,000 sediment cores over 40 miles of river in order to establish the areal and vertical extent of PCB contamination in the river. Dr. Benaman's tasks entailed geostatistical and deterministic interpolations, and also extensive communication of the delineation effort though reports, maps, and graphs.
Review of Remedial Investigations for Select Manufactured Gas Plant Sites *Con Edison* *New York, New York*	Dr. Benaman was involved with the review of remedial investigations conducted on various manufactured gas plant sites in New York City. The review includes the development of a conceptual site model to understand potential contamination of in-river sediments from land-side activities, as well as identification of data gaps.
Investigation of Mercury in Lavaca Bay *Aluminum Company of America (Alcoa)* *Port Lavaca, Texas*	Dr. Benaman was involved in the assessment of mercury in fish, water and sediment in Lavaca Bay, including a review of long-term trends after remediation. She was responsible for data analysis and management using GIS to identify and quantify mercury sources and the ultimate fate of mercury. Her duties included coordination and communication with other subcontractors and state agencies for data information; extensive data analysis; and the development of input parameters for the project's hydrodynamic, sediment transport, and chemical fate models.

Testimony Experience

PFAS Fate and Transport and Regulations *Confidential Client*	Dr. Benaman serves as a consulting expert for a confidential client related to the fate and transport of PFAS in the environment, as well as the impacts of developing PFAS regulations and guidance in various states and countries.
Illinois River Watershed, Oklahoma, Coordinating Expert *Poultry Industry/Attorney General Litigation*	Dr. Benaman served as the coordinating expert of over 11 expert witnesses for the Illinois River Watershed litigation. Work included review of all expert reports, coordination of review topics, and management of Anchor QEA's expert report submitted on behalf of the Poultry Industry Joint Defense Group.
Public Testimony on San Francisco Bay TMDL *Regional Water Quality Control Board*	Dr. Benaman provided expert witness testimony on February 13, 2008, on behalf of a regulated community regarding scientific basis of the TMDL development and impacts of assumptions on results.
Water Quality Impacts of a Parking Lot Expansion, Expert Witness *Hope in the City Church* *Austin, Texas*	Dr. Benaman provided expert witness testimony on behalf of Hope in the City Church regarding the water quality impacts of the Church's proposed parking lot expansion on a nearby receiving creek. Her testimony included an expert report investigating non-point source loads from the parking lot expansion and impact assessment of the receiving stream, a rebuttal report, deposition by the City of Austin's lawyer, and support to the litigating counsel on motions and declarations.
Lake Calhoun Water Quality Assessment, Expert Witness *Lake and Knox, LLC* *Minneapolis, Minnesota*	Dr. Benaman provided expert witness support to Lake and Knox, LLC regarding possible disposal options for pumped groundwater being discharged from their property. Dr. Benaman's support included the development of an expert report regarding possible options for the disposal of the water, as well as a series of rebuttal reports related to the environmental impact of the discharge on a local lake. She also provided technical support for settlement discussions.

Journal Reviewer

- American Society of Civil Engineers (ASCE) Journal of Hydrologic Engineering
- ASCE Journal of Water Resource Planning and Management
- ASCE Journal of Environmental Engineering
- Hydrological Processes

Invited Participation in Technical Workshops

"The Role of PFAS in Sediments in Fish Recovery" with J. Connolly, D. Glaser, E. Lamoureux, W. Ku, S. LaRoe, D. Opdyke, and D. Reidy. 2024 RPIC Professional Development Webinar. November 9, 2024.

"Site Characterization for Risk Assessment Modeling and Remedial Decisions" Lecture at Manhattan College. 59th Institute in Water Pollution Control. June 15, 2011

"Total Maximum Daily Loads: What General Electric Needs to Know." Full-day workshop given at General Electric Aircraft Engine. Cincinnati, Ohio. March 2002.

"Data Needs in Environmental Modeling." Full-day lecture given at ASCE Qual2E Workshop. Fort Washington, Pennsylvania. March 2002.

"Watershed Modeling and GIS." Full-day lecture given at Tufts University, TMDL Modeling Workshop. Boston, Massachusetts. June 2001.

"GIS in Environmental Risk Assessment". Pre-Conference Seminar presented at the 1998 ESRI Users National Convention, San Diego, California. July 1998.

"GIS in Water Quality Modeling". Seminar presented at Manhattan College Summer Institute in Water Pollution Control. Riverdale, New York. June 1997.

Presentations

The Influence of PFAS Regulations on Waste Disposal" with A. DeWitt. 2023 RPIC Federal Contaminated Sites National Workshop. Toronto, ON. November 29, 2023.

"The Role of PFAS in Sediments in Fish Recovery" with J. Connolly, D. Glaser, E. Lamoureux, W. Ku, S. LaRoe, D. Opdyke, and D. Reidy. 2023 Battelle Contaminated Sediments Conference. Austin, TX. January 10, 2023.

"PFAS and CERCLA: The Next Frontier?" with J. Connolly, D. Opdyke, and B. Henry. 2021 RPIC Federal Contaminated Sites National Workshop. Virtual. November 17, 2021.

"PFAS and CERCLA: The Next Frontier?" with J. Connolly, D. Opdyke, and B. Henry. Sediment Management Work Group Fall Symposium. Washington, D.C. October 30, 2019.

"Early Assessment of the Overall Effectiveness of the Upper Hudson River Remedy" With J. Connolly, E. Lamoureux, J. Haggard and R. Gibson. 2019 Battelle Contaminated Sediments Conference. New Orleans, LA. February 12, 2019.

"PFASs: Fate, Transport, Bioaccumulation, and Remediation" Short Course with D. Opdyke, J. Anderson, and J. Durda. In collaboration with Integral Consulting. 2019 Battelle Contaminated Sediments Conference. New Orleans, LA. February 11, 2019.

"Bioaccumulation of PFOS in Freshwater Fish: Evolving Perspectives on an Emerging Contaminant" With S. LaRoe, J. Connolly, and D. Opdyke. Association of Environmental Health and Sciences. 31st Annual International Conference on Soils, Sediments, Water, and Energy. Amherst, MA. October 20, 2015.

"Applying the New Vision for the Clean Water Act Section 303(d) Program: Accounting for Ongoing Restoration at Contaminated Sediment Sites." With T. Stiles and E. Darby. Battelle International Conference on Remediation of Contaminated Sediments. New Orleans, LA. January 15, 2015.

"Environmental Models and Source Allocation." Joint American Bar Association CLE Conference. Beaver Creek, CO. February 1, 2014.

"TMDLs at Sediment Cleanup Sites: The 4(b) Process" Battelle International Conference on Remediation of Contaminated Sediments. Dallas, TX. February 6, 2013.

"Understanding Remedial Design Effectiveness by Analyzing Design Quality" with A. Clough and J. Connolly, PhD, P.E. Battelle Contaminated Sediments Conference. New Orleans, LA. February 10, 2011.

"Understanding Remedial Design Effectiveness by Analyzing Design Quality" with A. Clough and J. Connolly, PhD, P.E. Society for Environmental Toxicologists and Chemists Annual Meeting. Portland, OR. November 11, 2010.

"Modeling the Response of the Upper Hudson River to Dredging and Natural Recovery" with J. Connolly, PhD, P.E., P. Israelsson, PhD, P. Oates, PhD, B. Lamoureux, and L. Zheng, PhD. Sediment Management Work Group. Green Bay, WI. October 6, 2010.

"Evaluating Policies Using a Proactive Basin Management Tool" With Emily Chen, P.E., Harry Zahakos, P.E., and James Patek, P.E. In cooperation with the Lower Colorado River Authority

American Water Resources Association Annual Conference. Seattle, WA. November 13, 2009.

"Adaptive Implementation for Improved Water Quality Management: When Does it Make Sense? A Follow Up to the 2001 National Research Council TMDL Report." With P. Freedman, K. Reckhow, and L. Shabman. Texas Water 2008, San Antonio, Texas. March 28, 2008.

"Adaptive Management at Contaminated Sediment Sites: Opportunities and Challenges." Benaman, J., and J. Connolly. Optimizing Decision-Making and Remediation at Complex Contaminated Sediment Sites. Sediment Management Work Group Conference. New Orleans, Louisiana. January 8 to 10, 2008.

"Adaptive Management in Watersheds and Water Resources: Opportunities and Challenges." Benaman, J. Texas Water Conservation Association Mid-Year Conference. Galveston, Texas, June 4 to 6, 2008.

"Water Quantity and its Impact on Quality: An Approach to Assessing In-stream Flows for a Texas River." With L. Manning and S. Fletcher. American Water Resources Association Annual Meeting. Albuquerque, New Mexico. November 13 to 16, 2007.

"Intersection between Water Quality and Water Rights: Emerging Legal Issues and Technical Challenges." Benaman, J., and J. McQuaid. 2007 Annual Texas Water Law Conference. Austin, Texas. September 10 to 11, 2007.

"Sensitivity and Uncertainty Analysis of the QUAL-TX Model to Aid in the Management of the Lower Colorado River, Texas." With P. Mugunthan, D. Opdyke, E. Chen, L. Manning, and S. Fletcher. WEF TMDL 2007 Conference. Published in proceedings. Seattle, Washington. June 24 to 27, 2007.

"Adaptive Implementation for Improved Water Quality Management: When Does it Make Sense? A Follow Up to the 2001 National Research Council TMDL Report." With P. Freedman, K. Reckhow, and L. Shabman, AWRA Adaptive Management Conference. Abstract published in proceedings. Missoula, Montana. June 26 to 28, 2006.

"Legacy Pollutants, Contaminated Sediments and TMDLs: Applying Better Science with Limited Budgets." Third International Conference on Remediation of Contaminated Sediments. Abstract published in proceedings. New Orleans, Louisiana. January 24 to 27, 2005.

"Lower Colorado River Authority-San Antonio Water System Water Project Environmental Studies: Maintaining Quantity for Quality's Sake." Invited Presentation. Flows for the Future 2005. Texas State University River System Institute. San Marcos, Texas. November 1, 2005.

"Overcoming Data Limitations to Establish Nitrate and Ammonia TMDLs for Stone Dam Creek, Arkansas." With D. Opdyke and J. Franks. WEF TMDL 2005 Conference. Published in proceedings. Philadelphia, Pennsylvania. June 26 to 29, 2005.

"The Application of GLUE to Estimate Uncertainty." Uncertainty Analysis: Tools and Methodologies to Support TMDL Development and Adaptive Implementation. WEF TMDL 2005 Conference. Philadelphia, Pennsylvania. June 26 to 29, 2005.

"A Better Way to Conduct TMDLs on a Shoestring Budget." With J. Connolly and K. Russell. WEF TMDL 2003 Conference. Published in proceedings. Chicago, Illinois. November 16 to 19, 2003.

"Sensitivity and Uncertainty Analysis of a Distributed Watershed Model for the TMDL Process." With C.A. Shoemaker. Published in proceedings. WEF 2002 TMDL Conference. Phoenix, Arizona. November 13 to 16, 2002.

"Customization of BASINS for the North Sandy Pond Watershed." With K.T. Russell, and J.R. Rhea. Published in proceedings. WEF Watershed 2002 Conference. Ft. Lauderdale, Florida. February 24 to 27 2002.

"A Calibration, Validation, and Sensitivity Analysis for a Distributed Watershed Model: Hydrology and Sediment Transport in a Northeastern Climate." With C.A. Shoemaker. Abstract published in proceedings. American Geophysical Union Annual Meeting. San Francisco, California. December 10 to 14, 2001.

"Modeling Non-Point Source Pollution using a Distributed Watershed Model for the Cannonsville Reservoir, New York." With C.A. Shoemaker and D.A. Haith, ASCE 2001 World Water Environment Congress. Orlando, Florida. Published in proceedings. May 20 to 24, 2001.

"The Use of GIS in the Development of Water Quality Models." With J.D. Mathew. 2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management. Sponsored by American Society of Civil Engineers. Minneapolis, Minnesota. Published in proceedings. July 30 to August 2, 2000.

"A Critical Assessment of Watershed and Water Quality Models for the Texas TMDL Process." With G. Ward, D.R. Maidment, and W.K. Saunders, Published in proceedings. Watershed 2000. Sponsored by Water Environment Federation. Victoria, B.C., Canada. Published in proceedings. July 9 to 13, 2000.

"Hot Spots: A Figment of Our Interpolation – Methods and Uncertainty in Spatial Interpolation." Society of Environmental Toxicology and Chemistry 20th Annual Meeting. With J. Connolly. Philadelphia, Pennsylvania. November 14 to 18, 1999.

"GIS in Environmental Modeling." With J.D. Mathews. North East Arc Users Conference. Long Branch, New Jersey. September 1997.

Publications

Adaptive Implementation in the TMDL Program: A New Approach. Freedman, P., K. Reckhow, L. Shabman, **J. Benaman**, D. Schwer, and T. Stiles. WEF Water Practice. 2008.

Water Quality and Water Rights. McQuaid, J. and **J. Benaman**. Chapter 22 In Texas Law of Water Resources. TexasBar Books. 2009.

Adaptive Implementation of Water Quality Improvement Plans: Opportunities and Challenges. Shabman, L., K. Reckhow, M.B. Beck, **J. Benaman**, S. Chapra, P. Freedman, M. Nellor, J. Rudek, D. Schwer, T. Stiles, and C. Stow, Nicholas School of the Environment and Earth Sciences, Durham, NC, September 2007.

An Analysis of High-Flow Sediment Event Data for Evaluating Model Performance. **Benaman J.** and C.A. Shoemaker. Hydrological Processes 19(3): 605-620. 2005.

Calibration and Validation of Soil and Water Assessment Tool on an Agricultural Watershed in Upstate New York. **Benaman, J.**, C.A. Shoemaker and D.A. Haith. ASCE Journal of Hydrologic Engineering. 10(5): 363-374. 2005.

Methodology for Analyzing Ranges of Uncertain Model Parameters and Their Impact on the TMDL Process. **Benaman J.** and C.A. Shoemaker. ASCE Journal of Environmental Engineering 130(6): 648-656. 2004.

Uncertainty and Sensitivity Analyses for Watershed Models: Hydrology and Sediment Transport Modeling on the Cannonsville Reservoir System. **Benaman J.** Ph.D. Dissertation. Cornell University. Department of Civil and Environmental Engineering. January 2003.

A Robust Sensitivity Analysis Method for Complex Watershed Models with Application to the Cannonsville Basin. **Benaman, J.,** and C.A. Shoemaker. Published in Proceedings of ASCE World Water & Environmental Resources Congress 2003.

A Systematic Approach to Uncertainty Analysis for a Distributed Watershed Model. **Benaman, J.** Dissertation Proposal. School of Civil and Environmental Engineering. Cornell University. January 2001.

A Model of PCB Fate in the Upper Hudson River. Connolly, J.P., H.A. Zahakos, **J. Benaman**, C.K. Ziegler, J.R. Rhea and K. Russell. Environ. Sci. Technol. 34:4076-4087. 2000.

Effective Decision-Making Models for Evaluating Sediment Management Options. Connolly, J., J. Rhea, and **J. Benaman**. White paper. Sediment Management Workgroup. 1999.

Modeling of Dissolved Oxygen in the Houston Ship Channel using WASP5 and Geographic Information Systems. **Benaman J.**, N.E. Armstrong, and D.R. Maidment. Center for Research in Water Resources Electronic Report 96-2. University of Texas at Austin. August 1996.

Geochemistry, Mineralogy, and Stable Isotopic Results from Ala Wai Estuarine Sediments: Records of Hypereutrophication and Abiotic Whitings. Glenn, C.R., S. Rajan, G.M. McMurtry and **J. Benaman**, Pacific Science 49(4):367-399. 1995.

Committees and Advisory Boards

- National Academy of Engineers, Outstanding Young Engineer, Frontiers of Engineering Symposium Participant, 2011
- Water Environment Federation, Watershed Management Committee, 1999 to 2008
- Water Environment Federation, Watershed Conference Program Committee, 1999 to 2002
- Water Environment Federation, TMDL Science Issues Conference Committee, 2002 to 2004
- Texas Water Conservation Association, Water Quality Standards Committee, 2004 to 2009
- Water Environment Association of Texas, Cmtee Chair, Watershed Management Committee, 2007